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New and Improved Emission Models in the Finite-Element Gun Code MICHELLE

Eric M. Nelson
Los Alamos National Laboratory
Los Alamos, NM 87545

John J. Petillo
Science Applications
International Corporation
Burlington, MA 01803

Kevin Jensen
Naval Research Laboratory
Washington, DC 20375

Abstract: We continue to research and develop better emission models for gun codes. We describe our recent efforts to improve the thermal aspects of space-charge-limited emission, the transition from temperature-limited emission to space-charge-limited emission, and photoemission.

Keywords: gun code; beam optics code; space-charge-limited emission; photoemission.

While there are many examples of first-pass design success with MICHELLE [1][2], there remain devices that require better emission algorithms or specific user intervention. Our recent efforts have focused on the thermal aspects of space-charge-limited emission, the transition from temperature-limited emission to space-charge-limited emission, and photoemission.

Gridded guns motivate our interest in the first case, the thermal aspects of space-charge-limited emission. The default Child's law algorithm [3] in MICHELLE does not automatically apply a thermal correction factor, although this factor has always been available as an option. The default algorithm works well when this factor is negligible. But for a gridded gun, the emission algorithm samples the potential at points close to the cathode, points where the potential is on the order of 10V. Even though 10V is large compared to the electron temperature, about 0.1 eV, the thermal correction to the Child-Langmuir law can be 25% or more [4][5]. So one needs to include the thermal correction factor in such cases. We will discuss the correction factor and how it can be reliably applied in a gun code, not only for gridded guns but also for IOTs and low voltage guns.

For basic temperature-limited emission, MICHELLE users can directly specify the emitted current density, or they can specify parameters in the Richardson-Dushmann equation. When the current density approaches the space-charge limit, a Longo-Vaughan formulation with material-dependent parameters is desired [6][7]. Our original implementation was incorrect in that it did not compute the space-charge-limited current density separately, as the Longo-Vaughan formula intends. We will discuss how Longo-Vaughan is now implemented in MICHELLE and the alternatives we considered.

New theoretical models [8] for the process of photoemission have been developed recently in support of RF photocathodes for free electron lasers. MICHELLE's electrostatic time-domain model with an imposed RF field has unique capabilities for modeling the emission and the self fields near the cathode, and it can model non-relativistic photocathodes, including in particular some photocathode test stands for photoemission research. Models of relativistic photocathodes are possible, but our self-magnetic field model for this application needs to be validated. We will present the emission models added to the MICHELLE code for modeling RF photocathodes and some examples of how they are being used to model the effects of surface roughness.

Emission non-uniformity is a consequence of either geometrical structure (field-enhancement variation) or variation in coating coverage (work function variation). The former can cause a variation in emission current density by a factor of 2 for gyrotron dispenser cathodes. The latter is caused by non-uniform coverage of alkali or alkali-earth coatings on the cathode surface. Both occur over several length scales (sub-micron to tens of microns), and both affect the emission distribution, emittance, and other measures of beam. When photoemission processes are included, a proper account of both time-dependent laser effects and spatially varying emission characteristics becomes quite difficult. The effect of using a temperature-dependent photoemission model to simulate photoemission from a hemispherical surface for which the field enhancement varies by a factor of 3 is shown in Figure (2b) using simplified models developed to analyze experimental photoemission data.

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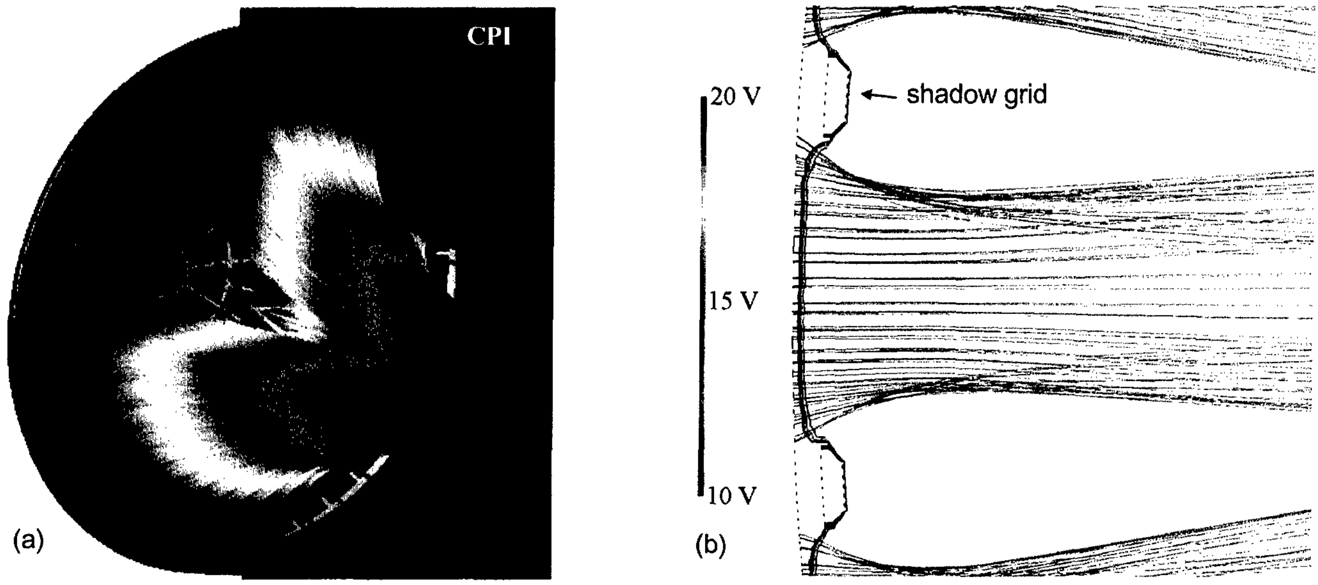

Figure 1. (a) A gridded gun with the particle orbits colored by energy. The shadow grid (yellow) behind the control grid (green) is very close to the cathode. (b) A detailed view of particle trajectories near the cathode and shadow grid, with potential contours ranging from 10–20 V superimposed. The emission algorithm must work close to the cathode and at low voltages to accommodate the geometric complexity of the gridded gun.

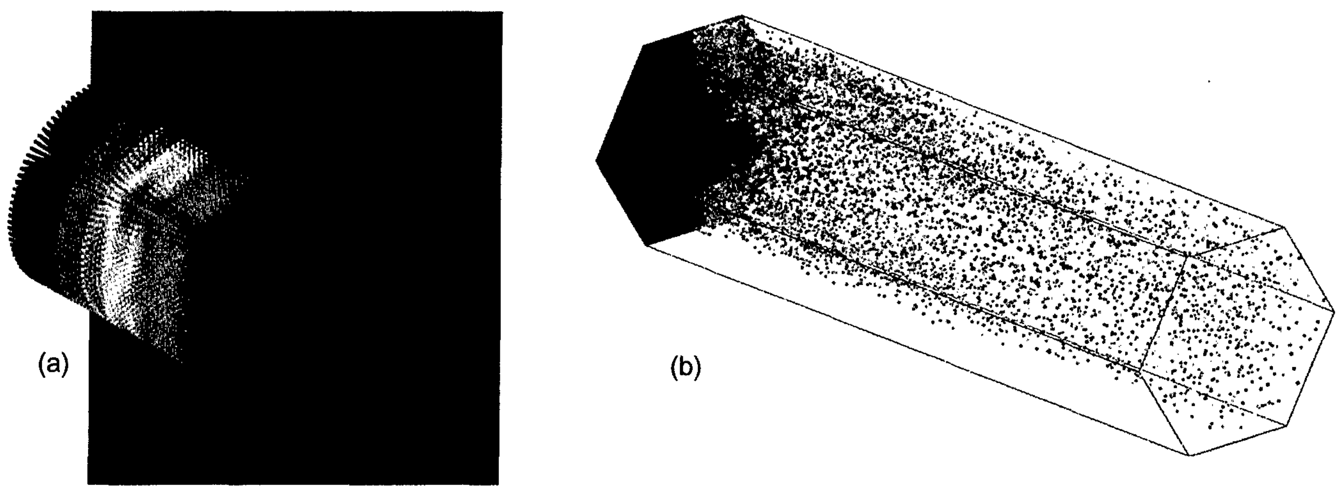

Figure 2. (a) A bunch, near the cathode, generated by a rippled laser pulse. The cutplane shows how the mesh is refined in the vicinity of the bunch. (b) A bump (red) on the cathode (green) simulates surface roughness. Particles are colored by charge in both cases.